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Optimal power distribution between the wheels of a mobile vehicle under different soil conditions

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Abstract

This work is dedicated to minimizing power consumption for a vehicle propulsion, with power distributed non-uniformly between axles under different soil conditions for wheels on the right and on the left side of the vehicle. We present a method of calculating minimal total power required for the driving wheels of the mobile vehicle, for different transmission types. We've compared total required power for most common methods of controlling power flows in transmissions of the mobile vehicle, such as implementing unlocked differential gears, limited-slip differentials and their full locking, and systems of optimal power control. This document includes an efficiency assessment in case of alternating specific load on axles under different soil conditions for right and left wheels. We have formulated requirements to controlling differential gears locking based on road conditions.

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1. Introduction

World science intensively deals with power distribution between mobile vehicle wheels in the frames of these vehicles theory [1–10]. Solving task of optimal power distribution between mobile vehicle wheels allows finding law of controlling power flows depending on vertical loads and traction resistance [11].

Let's discuss task of optimal distributing of power under different soil conditions.

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2. Task solving method

Let's assume that two axial AWD wheeled vehicle at some point of time moves with one side wheels on high traction soil (solid soil; $\lambda_1=\lambda_3=0.55$; $\varphi_{d1}=\varphi_{d3}=0.8$; where φ_{di} , λ_i — parameters, characterizing traction forming properties of the soil areas, contacting with wheel number i), and with other side wheels — on low traction soil (soft soil, ice, etc.; $\lambda_2=\lambda_4=0.55$; $\varphi_{d2}=\varphi_{d4}=0.4$).

Wheels are numbered according to [8] (Fig. 1). Resistance to motion factor is equal to $f=0.3$. Each wheel is loaded with vertical load with weight component of γ_i . Vertical load is equally distributed among wheels.

Conditions of uniform linear movement, [11]:

$$\left. \begin{aligned} V_1 \cdot (1 - \delta_1) &= V_c & V_2 \cdot (1 - \delta_2) &= V_c \\ V_3 \cdot (1 - \delta_3) &= V_c & V_4 \cdot (1 - \delta_4) &= V_c \\ \gamma_1 \varphi_1(\delta_1) + \gamma_2 \varphi_2(\delta_2) + \gamma_3 \varphi_3(\delta_3) + \gamma_4 \varphi_4(\delta_4) - (\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4) f &= 0 \end{aligned} \right\}, \quad (1)$$

where V_i — theoretical wheels speeds; V_c — actual vehicle centre of gravity speed; slipping coefficient δ_i and specific traction loads — φ_i , relate to soil parameters by equations

$$\varphi_i(\delta_i) = \varphi_{di} \cdot \tanh\left(\frac{\delta_i}{\lambda_i}\right). \quad (2)$$

Diagrams of slipping and specific traction loads dependences on these soils are presented on Figures 2 and 3.

Depending on transmission scheme, system of equations (1) is supplemented by equations of constraints. For the AWD vehicle with transmission with non-locked symmetrical interaxial and interwheel low friction differential gears we should add equations of equality of the traction loads at wheels of each axis and sums of traction loads between axes:

$$\left. \begin{aligned} \gamma_1 \varphi_1(\delta_1) - \gamma_2 \varphi_2(\delta_2) &= 0 \\ \gamma_3 \varphi_3(\delta_3) - \gamma_4 \varphi_4(\delta_4) &= 0 \\ \gamma_1 \varphi_1(\delta_1) + \gamma_2 \varphi_2(\delta_2) - \gamma_3 \varphi_3(\delta_3) - \gamma_4 \varphi_4(\delta_4) &= 0 \end{aligned} \right\}. \quad (3).$$

For the AWD vehicle with transmission with locked symmetrical interaxial and interwheel differentials we should add equations of equality of ideal velocities for all wheels:

$$\left. \begin{aligned} V_1 - V_2 &= 0 \\ V_3 - V_4 &= 0 \\ V_1 + V_2 - V_3 - V_4 &= 0 \end{aligned} \right\}. \quad (4).$$

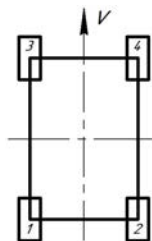


Fig. 1. Wheels numbering

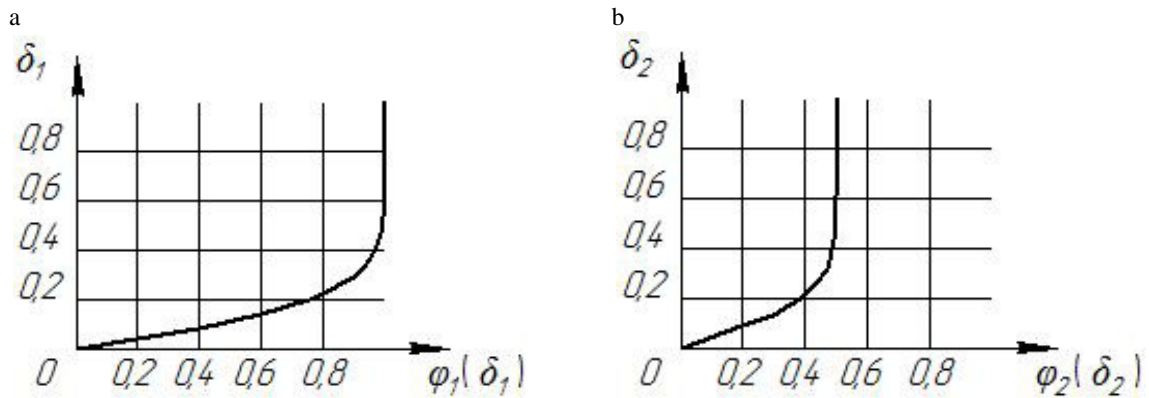


Fig. 2. (a) slipping dependence of specific traction force hard soil; (b) slipping dependence of specific traction force soft soil

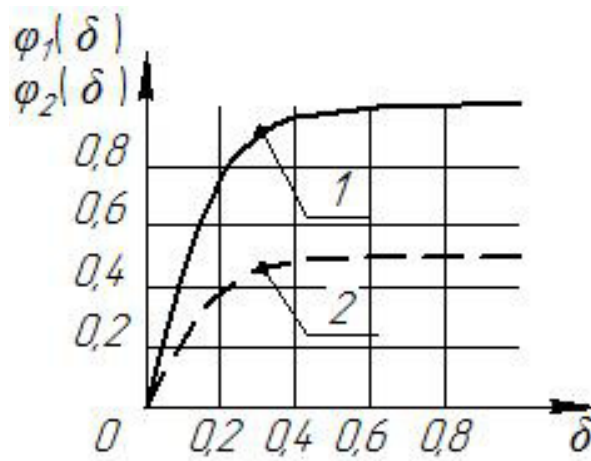


Fig. 3. Specific traction force dependence of slipping

For the AWD vehicle with transmission with non-locked symmetrical interaxial differentials and interwheel limited-slip differentials we should add equations of sums of traction loads at axles. Draw forces relations for each of the axles will be determined by differentials torque bias K_d :

$$\left. \begin{aligned} \gamma_1 \varphi_1(\delta_1) + \gamma_2 \varphi_2(\delta_2) - \gamma_3 \varphi_3(\delta_3) - \gamma_4 \varphi_4(\delta_4) &= 0 \\ K_d \gamma_1 \varphi_1(\delta_1) - \gamma_2 \varphi_2(\delta_2) &= 0 \\ K_d \gamma_3 \varphi_3(\delta_3) - \gamma_4 \varphi_4(\delta_4) &= 0 \end{aligned} \right\}. \quad (5)$$

For AWD vehicle with transmission with interaxial low slipping differential we should add equations of equality of the traction forces at each of the axes. Relations between sums of the traction forces between axes are determined by interaxial differential torque bias K_d :

$$\left. \begin{aligned} \gamma_1 \phi_1(\delta_1) - \gamma_2 \phi_2(\delta_2) &= 0 \\ \gamma_3 \phi_3(\delta_3) - \gamma_4 \phi_4(\delta_4) &= 0 \\ K_d(\gamma_1 \phi_1(\delta_1) + \gamma_2 \phi_2(\delta_2)) - (\gamma_3 \phi_3(\delta_3) + \gamma_4 \phi_4(\delta_4)) &= 0 \end{aligned} \right\}. \quad (6)$$

3. Calculations results

Following (Fig. 4 and 5) indicates calculations results for vehicles, equipped with transmissions with different power distributing units.

Curve (Fig. 4) demonstrates that total power on driving wheels essentially depends on scheme of its distribution. Full differential lock allows decreasing total power on driving wheels up to minimum, allowed by power distribution control system. Partial lock allows significant decreasing of power on driving wheels but does not allow its minimal value. Transmission without differential locking is less effective: while motion resistance factor f increases, relation between total power and minimal value increases and increases without limit under above conditions when $f = 0.46$.

The curve (Fig. 5) shows that implementing of the interaxial low slipping differential with constant torque bias instead of the low friction differential leads to decreasing total specific power on driving wheels under sufficiently great difference between loads on axles. For each constant torque bias there is a vertical axis load value, under which total specific power becomes lower than for non-locked differentials, so partial unlocking becomes reasonable (points of curve 1 crossings with curves 2, 3, and 4).

Each of the curves 2, 3 and 4 has a minimum upper than curve 5. So each torque bias value has specific vertical load on axles γ_{onm} under which total specific power on the wheels becomes maximum. Minimal values of the total specific power are the same for different constant values of the torque bias, and they are higher than value, assured by the power control system or by full differentials locking. In other words, for each value of the specific vertical load on axles there is a torque bias, assuring minimum specific power on driving wheels. So, we can decrease total specific power, spent for moving the vehicle, by controlling the torque bias.

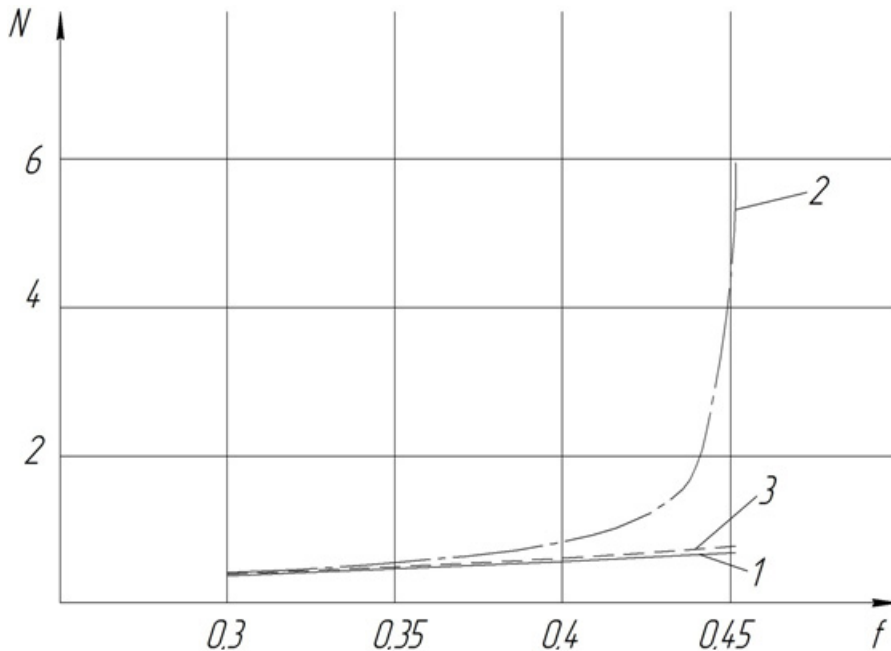


Figure 4. Dependences of total specific power on driving wheels on motion resistance coefficient: 1 — for vehicle with optimal distribution of power or with all differentials locked; 2 — for vehicle with non-locked differentials; 3 — for vehicle with inter wheels low slipping differentials.

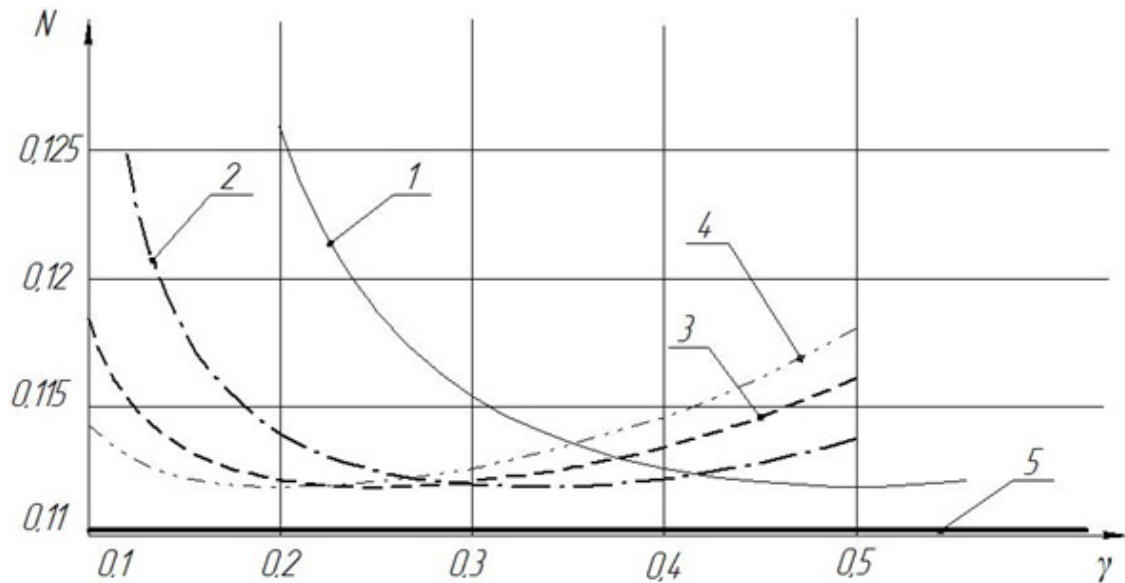


Figure 5. Dependences of the total specific power (N) on driving wheels from load on rear axle (γ): 1 — for vehicle with non-locked differentials; 2, 3, and 4 — for vehicles with interaxial low slipping differentials with constant torque bias 2, 3, and 4 accordingly; 5 — for vehicle with optimal power distribution or with all locked differentials.

4. Conclusion

In that way solving the task of external resistances power minimization allows not only evaluating effectiveness of implementing different kinematic schemes and transmission designs taking into account nonuniformity of load distribution between the vehicle wheels and different soil conditions, but also allows formulating requirements to controlling differential locking under different road conditions.

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